Micro-CHP in various futures

FROM MICRO OPPORTUNITIES TO MACRO CHANGES

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ABSTRACT

The idea of micro-CHP (Combined Heat and Power generation) is gaining more and more attraction, and more and more momentum. The basic idea is small scale CHP systems for in house purposes, generating both electricity and heat, with high overall energy efficiency. Taking this as a starting point, a variety of more or less sophisticated concepts can be developed. Five concepts are presented in this paper.

The opportunities for each of these concepts largely depend upon the characteristics of the energy system in which the micro-CHP concepts have to find their way. To what extent will climate policies be a constraint? What will liberalisation and market forces do? What about consumer preferences? The answers to these questions can be decisive.

The opportunities of the five concepts are analyzed in two ways: top-down (with the help of four scenarios) and bottom-up (with the help of an analysis of key factors that are decisive for successful market introduction of new energy options). These key include Technology, Economy, Markets, Politics, Legal aspects, and Ethics and society (TEMPLE-analysis).

Innovative concepts based on the core technologies of micro CHP, can play an important role in bridging the gap towards a fully sustainable energy system. Success or failure of these concepts cannot predicted with 100% certainty, however, critical factors can be detected, and – to some extent at least – can be influenced. For a successful introduction of CHP concepts, not only technological improvements are important, but also political and societal factors should be addressed.
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1. INTRODUCTION

Can a small-scale innovation turn the energy system upside down in due time? That might be the case for so-called micro-scale combined heat and power generation, in short micro-CHP. But whether this revolution indeed will take place, largely depends on the macro-trends in the world energy system, and on the way the industry is able to find strategic solutions that are robust for a variety of yet uncertain futures that may occur.

The concept of micro-CHP is simple, and we will not go into much detail here. The basic idea is to produce both heat and electricity on micro, i.e. household, scale. The technical hardcore is, currently, a Stirling engine, which on the longer term can be replaced by a fuel cell. Natural gas is the preferred fuel, at least in the beginning of this transition, which over time can be partly or completely replaced by ‘bio-based gas’ (gasification of biomass, followed by cleaning and other treatments) and/or hydrogen.

Taking this as a starting point, a number of broader concepts can be developed. Each of these may have a smaller or larger impact on the energy system, and vice versa: the macro-development of energy systems may be more or less favourable for one or more of these concepts.

In this paper, we will elaborate some concepts that can be built on the basis of the micro-CHP technology as the technological backbone, and analyze the advantages, disadvantages and question marks that come along with these concepts in a wide range of future energy scenario’s. Also a bottom-up analysis of some factors that can play key roles in the successful introduction of micro-CHP concepts is presented. The paper concludes with an agenda for research, development and policy making.

2. A RANGE OF MICRO-CHP CONCEPTS

Building on the core-technology of a both heat and power generating system, a number of key concepts can be imagined. Each of the concepts fits into and may influence a larger part of the total energy system, beginning with the simple heat and power generator in a household, and ending with the possibility of transforming the (linear) energy supply and demand chain into a far more decentralized system where supply and demand are closely intertwined.

The following concepts are interesting and feasible on the shorter or longer term:

1. **Home Alone.** This is the basic version of a heat and power generator (Stirling as a start, may be fuel cells in the future), replacing ‘classic’ heating systems at home. The scale of the system is such that heat can be used as much as possible (‘heat-led’ operated), electricity mainly being a by-product for own personal use. In that case, no heat storage is needed.

2. **Home and Storage.** If some heat storage equipment is added, the capacity of the system can be higher, yielding higher heat and electricity production. Heat can be stored for later use, and surplus electricity may be delivered to the grid. Still, in this concept it’s the household that owns the equipment and decides on production and demand.
3. Home Plus. In this concept, some energy tools and technologies are added to the CHP-core, and to develop an integrated semi-independent home energy system. The only limiting factor is fantasy, many technologies are there already. Solar heating and photovoltaic solar energy may be part of this concept, a small-size wind turbine, demand side management equipment can be quite useful (e.g. in-house peak shaving programs in order to adapt the demand pattern to the supply pattern), energy saving technologies are an inevitable part. Even combinations with hybrid cars, accumulating electricity during the night, can be sought. And last but not least: the whole in-home energy infrastructure may be a different one, by replacing the 230 V AC system that is transformed into low voltage DC per television, radio, halogen light bulb and so on, losing a lot of energy, by a low voltage DC electricity system. Local circumstances will to a large extent determine the technologies that can be added on to the CHP-system.

4. Virtual Power Plant (VPP). A larger number of micro-CHP systems including heat storage, are connected through an intelligent ICT-network, and operated as if it were a power plant. The electricity demand and electricity prices are leading here (‘electricity-led design and operations’). Heat, in this concept, can be seen as a by-product. As a consequence, the system as a whole should be operated, may be even owned, by a ‘utility’: an existing energy company or a newly formed enterprise in which a large number of micro-CHP-owners participate.

5. Transforming the System. In this concept, micro-CHP/Virtual Power Plant is considered to be the front runner of a radical change in the way energy systems operate. The classical linear system of fuel – conversion/power production – transport – end use is, in this view, replaced by the idea of a decentralized intelligent network (or combination of networks), where production and consumption of energy are intertwined, and alternate over time. This concept is based on the long-term perspective in which an energy system with a large share of decentralized renewable energy sources is inevitable. Such a system requires a flexible grid, heat and electricity storage, energy efficiency solutions, demand side management and the like. In a way, this concept is the macro counterpart of concept number 3, the Home Plus concept.

The higher the concept number, the larger the system in which it operates and in which it may catalyze changes. Also technical, operational, organizational and policy aspects may vary per concept, as well as the acceptance of each of the systems.

Key advantages may be:
- higher energy efficiency,
- money saving,
- increased customer satisfaction,
- benefits for society at large,
- transition to a sustainable energy system.

Whether these potential benefits can indeed become reality, depends on the technical-economical development of the concepts, and on the (energy) world within which the concepts play their role.

While future worlds will be analyzed in the next section, we will discuss some of the potential advantages below.
The energy efficiency potential is highest when the system is designed on the basis of heat demand, and even better with heat storage, while electricity is a by-product, mainly for own in-house use, replacing electricity drawn from the grid. The financial potential, however, is highest when electricity production is leading, and when with the help of intelligent systems, electricity can be produced at moments of high power prices. Particularly linking a large number of individual micro-CHPs and operating the whole as a virtual power plant fits within this strategy. But without any additional measures, the energy efficiency potential decreases, since the virtual power plant has to compete on the electricity market with modern steam and gas turbines with an efficiency of around 60%. Energy storage (heat, or even better but technologically and economically more difficult electricity, or any other option like hydrogen) can help bridging the gap between energy optimization and financial optimization, combining the best of both worlds.

This goes for the basic ingredients of all concepts described above. Added-on options in the more far-reaching concepts have, of course, their own characteristics, but they do not fundamentally change the dilemma energy optimization versus financial optimization. Actually, these concepts basically seek to find other advantages, such as:
- increasing customer satisfaction
- addressing niche market opportunities, like the market for innovators and early adopters of new energy options
- finding strategic opportunities in the transition process towards a sustainable and more decentralized energy system

These advantages may in the beginning of the development of a concept be helpful to define and claim a market position, and may on the longer term also pay-out in terms of energy efficiency, economics, or both.

We will now shift the spotlight from the concepts and their advantages and challenges to the futures in which they will have to find their opportunities. There is not only a range of concepts, there is also a range of futures, as will be outlined below.

3. A RANGE OF FUTURES

The future is not predictable, almost by definition. That does not mean, however, that useful thought about the future are impossible. A good way of dealing with an unknown future is scenario analysis, or an analysis of storylines as a more qualitative approach, but with the same idea. In this section, we will analyze the opportunities for the micro-CHP concepts in a top-down way: taking scenarios or future worlds as a starting point, we will investigate what concepts fit best.

A lot of scenarios have been developed for energy systems. For our analysis, we will use the scenarios that have been presented by the Dutch Environmental Assessment Agency, in the so-called Sustainability Outlook. This study analyzes four different world views, in each of which a consistent philosophy of values, preferences, change mechanisms and driving forces are elaborated. These four philosophies have also empirically been tested, indicating that they indeed are recognized as possible world perspectives by politicians and the public at large. In these scenario’s, there is one tendency towards more efficiency or towards more solidarity, and another tendency towards more globalization or more regionalization. This gives the four world views as outlined in Figure 1.
The energy policy mechanisms corresponding with these scenarios are depicted in Figure 2.

In the A1 world of markets and globalization, changes are good that there is no particular concept that is the winning one. Since preferences, but also policies, will vary per region and probably also over time, many concepts may be able to find some market niche somewhere.
There will be a preference for economic efficiency, driving towards electricity driven concepts rather than to energy driven concepts. If there is one potential winner in this world, it may well be concept number 4, the virtual power plant, operated in a high-tech way.

In the B1 world of Our Common Future, markets under social and environmental constraints, the more sustainable and energy efficient concepts are likely to get the best opportunities. Internalization of social and environmental costs favours innovative sustainable solutions. The Home Plus concept and the Transforming the System concept can be expected to be the winners.

The A2 world is dominated by regionalization and security of supply issues. Particularly those concepts that are flexible in terms of fuel choice and that help becoming more independent of fossil fuels may be among the winners. Fear for insecurity of supply may lead to a shift in fuel mix. For gas, being the micro-CHP fuel par excellence, tendency will be towards domestic gas, LNG, and bio-based and-or coal-based gases. Home Alone and Home and Storage may be attractive concepts in this world.

In the B2 world, emphasis will be on energy efficient systems, and local applications. People in this world are willing to take local responsibility for solving global problems. Willingness to pay for energy saving and sustainable options is higher than in any of the other worlds. This particularly favours concepts like Home and Storage and may be even more the Home Plus concept.

Searching for potential winners in the four scenarios, the Number 1 and Number 2 concepts in these scenarios are summarized in Figure 3.

In this analysis, the Home-based systems (concepts 1, 2 and 3) go well in most of the scenarios. These options are rather robust in terms of unknown futures, in which uncertainty...
the industry needs to decide what options should be developed with highest or relatively low priority. The Virtual Power Plant VPP (concept 4) and Transforming the System (number 5) can be characterized as high gain, high risk concepts: they may be absolute winners in certain futures, but fail to play a good role in others. It also becomes clear that energy storage (heat, electricity, gas or liquids) bridges the gaps between the different futures. The better the energy storage technology, the more robust the concept in which it is used.

4. MICRO-CHP IN THE TEMPLE

In this section, we will look at micro-CHP concepts from a slightly different angle. The analysis is ‘bottom-up’: taking the concepts as a starting point, we will establish what key factors should be influenced in order to make a concept viable. These factors are summarized as TEMPLE:

- Technology
- Economy
- Markets
- Politics
- Legal aspects
- Ethics and society

Technology

As to technology, current state of the art for micro-CHP is the Stirling engine, which is quite useful for the experimental and market introduction phase, but in time radical changes may be needed. Particularly fuel cell technology may be such a radical change. Switching to different technologies will also lead to a different heat/electricity ratio, which is quite high (about 5 - 9) for the Stirling engine and much lower fuel cells (1 – 2, depending on the fuel cell type), gas engines taking an in-between position with 3 as a typical heat/electricity ratio (a.o. ref. 1). Usually, gas engines operate at higher capacities. Stirling engines therefore are preferable in home systems, while fuel cells will be the more interesting technology for more sophisticated concepts, such as the Virtual power plant and Transforming the System. Concepts, as it shows, are not technology neutral: with changing technologies, more sophisticated concepts will become increasingly attractive.

Economy

The Economy of a concept is partly dependent on the technology that is applied, partly on the consumer’s willingness to pay for certain features, and partly on external parameters such as gas and electricity prices. Willingness to pay can expected to be higher when customer satisfaction is better, and to some extent when sustainability is higher (this may vary per scenario/future world). Gas prices can to some extent be influenced. Where gas is relatively expensive for households, it can be argued that a series of interrelated micro-CHP systems should be seen as a power plant, and gas prices should be accordingly. Electricity prices in a growing number of countries are market prices, varying per year and even per second. The more intelligent the operator of a micro CHP or VPP, the higher the revenues on the electricity market will be. These gas and electricity prices therefore are particularly relevant for the more sophisticated concepts like Home Plus, VPP and Transforming the System.
Markets

The way Markets develop is always difficult to predict in the beginning of a market introduction. The overall performance of the system (concept) is, of course, an important factor for successful market introduction, and so are the some of the already mentioned external parameters influencing the economy of the concept. Often, market introduction may begin with niche markets: relatively small and relatively protected opportunities in the market, created by e.g. early adopters of innovations, and/or specific policy measures that temporarily favour a certain type of technology. Market introduction of the more basic concepts 1 (Home Alone) and 2 (Home and Storage) are relatively easy, since they merely replace existing, well-known applications. Usually, additional tricks and options will also create more difficulties in the early stages of market introduction. In that sense, particularly concepts 3 (Home Plus) and 5 (Transforming the System) can be seen as longer term perspectives.

Legal aspects

Legal aspects will on the long term not be problematic: if there are enough advantages, and if there is a growing coalition of parties who have a stake in the successful introduction of micro-CHP concepts, laws can and will be changed as necessary. But it may take time. Meanwhile, there may be short term barriers, ranging from the right for households to produce electricity for the grid, via tariffs, to liability issues and the charges that should be paid for back-up capacity. The more basis concepts will probably face less legal problems than the more sophisticated ones.

Ethics and society

Ethics and society refer to the general perceptions of and attitudes towards new technologies, both on an individual level and on a more general level. The nuclear energy debate in the seventies and eighties of the last century, clearly showed the impact of attitudes and perception on energy options. The current discussion on the availability and sustainability of biomass indicates that perceptions and attitudes still matter. Could they also influence the position of micro-CHP concepts? At a first glance, none of the concepts seems controversial on the short term. On the long term, the use of hydrogen in the built environment may become an issue because of safety aspects. Also the use of bio-based gas as a micro-CHP fuel on the longer term may become controversial, if a growing biomass consumption leads to competition with food production, and nature and biodiversity protection. These controversies, however, are more related to fuels than to the micro-CHP concepts in a narrower sense.

5. R & D, MARKET INTRODUCTION AND POLICY AGENDA

The top-down scenario and bottom-up TEMPLE analyses provide ideas for a Research and Development, market introduction and policy agenda.

Looking at the challenges from a micro-CHP technologies and concepts developer, choices are rather difficult. How to best anticipate future trends and developments while the future is highly uncertain? The first part of the strategy is to focus on robust options, that may survive or even flourish in a wide range of futures. The Home and Storage concept may well be among the winners in any of the future scenarios.
A corner stone to all options is energy storage, which helps bridging the tension between priority for energy efficiency on the one hand and economics on the other. Intensifying R&D in energy storage is therefore highly recommended.

Developing more sophisticated concepts may be quite challenging, but also more risky. Close co-operation with other parties will be needed for financial (risk sharing) and technological reasons: particularly energy companies in case of the virtual power plant, and innovative engineering companies in case of the Home Plus concept. The Transforming the System concept even requires a broader coalition of actors working together to pave the way: non-governmental organizations, energy companies, policy makers and others.

Co-operation, therefore, is another corner stone to the strategic development of micro-CHP concepts. Co-operation may take place at the supply side of the concepts (technology and concept driven), but also on the demand side, e.g. by implementing procurement programs. In these programs, a large group of customers can specify quality and cost characteristics, and sign-up as buyers of the product when these requirements are met. In this way, a less risky market introduction strategy can be followed.

So far, much emphasis has been on technological development (technology push). As the basics of the micro-CHP concepts become more clear, a shift towards market pull will be needed. As a first step, it is important to better know the future customers. As a second step, questions on changing ‘external’ parameters should be addressed: what are long term learning curves for the variety of technologies that may play a role in the Home Plus concept? Are there any possibilities for lower gas prices when a large number of units is operated as a virtual power plant, competing e.g. with Steam and Gas Turbines? Can special financial arrangements be found for tariffs for micro-CHP power fed into the grid? And how should micro-CHP concepts be treated within the emission trading scheme in the EU? The outcome of these and other policy issues are highly relevant for the future of micro-CHP based concepts. Here, again, a strong coalition of actors embracing the promises of one or more concepts will be indispensable.

Looking at a development trajectory over time, it becomes clear that the first steps concentrate on improving existing technologies, to be used for the more simple concepts Home alone and Home plus storage. These concepts can be the stepping stones to the more sophisticated concepts, keeping options open as long as possible for reasons of flexibility and dealing with uncertainties.

Micro-CHP concepts, particularly the more sophisticated ones, have the potential of transforming the energy system as a whole, on the long term, but not by itself alone, and not in all imaginable futures. The gas industry can be catalyst for the changes described above, elaborating each of the concepts, analyzing long term potentials, and taking responsibility for creating coalitions that are strong enough to take over the initiative and help gaining momentum.
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